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The project goals have been to provide enhanced real-time graphics generation capacity, computational power, and real-time audio signal processing capability for the Virtual Environment Research, Interactive Technology, And Simulation (VERITAS) facility, making it better suited to the demands of DoD-relevant research projects on human performance in complex environments. VERITAS is owned by Wright State University, but housed at Wright-Patterson AFB. It includes a *CAVE*™, which is an immersive, wide field-of-view, stereoscopic, real-time interactive display system, allowing the user to move through virtual environments with minimal encumbrances. The *CAVE*™ is controlled by a *Silicon Graphics Onyx*™ computer with *InfiniteReality*™ graphics. The high-fidelity simulations in this facility allow a variety of questions related to human effectiveness to be addressed. The DURIP funds were used to purchase three, high-performance computer subsystems: a multiprocessor computational subsystem, a graphics generation subsystem, and an acoustics generation subsystem. These subsystems provide critical capabilities for computationally intensive, real-time-constrained applications, including simulation, virtual environments, auditory and visual displays, motor control, and human perception and cognition. This instrumentation has supported specific funded DoD projects investigating: 1) display and control representations for UAV operation, and 2) binaural and spatial hearing.

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Instrumentation to Enhance DoD-Relevant Research on Cognitive Workload in Uninhabited Aerial Vehicles, Image Exploitation, and Spatial Hearing

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ABSTRACT

The project goals have been to provide enhanced real-time graphics generation capacity, computational power, and real-time audio signal processing capability for the Virtual Environment Research, Interactive Technology, And Simulation (VERITAS) facility, making it better suited to the demands of DoD-relevant research projects on human performance in complex environments. VERITAS is owned by Wright State University, but housed at Wright-Patterson AFB. It includes a *CAVE*™, which is an immersive, wide field-of-view, stereoscopic, real-time interactive display system, allowing the user to move through virtual environments with minimal encumbrances. The *CAVE*™ is controlled by a *Silicon Graphics Onyx*™ computer with *InfiniteReality*™ graphics. The high-fidelity simulations in this facility allow a variety of questions related to human effectiveness to be addressed. The DURIP funds were used to purchase three, high-performance computer subsystems: a multiprocessor computational subsystem, a graphics generation subsystem, and an acoustics generation subsystem. These subsystems provide critical capabilities for computationally intensive, real-time-constrained applications, including simulation, virtual environments, auditory and visual displays, motor control, and human perception and cognition. This instrumentation has supported specific funded DoD projects investigating: 1) display and control representations for UAV operation, and 2) binaural and spatial hearing.

OVERVIEW

The goals of this project have been to provide enhanced real-time graphics generation capacity, computational power, and real-time audio signal processing capability for the Virtual Environment Research, Interactive Technology, And Simulation (VERITAS) facility. VERITAS was originally constructed using funds from the Ohio Board of Regents and Wright State University. The Air Force Research Laboratory (AFRL), based on long-term positive collaborations with Wright State University, provided space to house the facility. Because of budget constraints the initial hardware and software configuration for the facility had limited capability and was somewhat dated when installed. The DURIP funds, along with costsharing funds from Wright State University and the Ohio Board of Regents Research Challenge Fund, and additional funds from AFOSR[F49620-95-1-0106], were used to purchase three state-of-the-art, high-performance computer subsystems: a multiprocessor computational subsystem, a graphics generation subsystem, and an acoustics generation subsystem. Simultaneously, additional funds from AFOSR [F49620-97-1-0231], along with costsharing from Wright State University and the Ohio Board of Regents Action fund, were used to purchase a second multiprocessor computational subsystem, haptic interfaces, a control PC for the haptic interfaces, and a variety of software. Currently, the facility is well-suited to most of our planned work on display and control designs to reduce cognitive workload in UAV operation and will aid our work on auditory displays. We plan to continue our efforts to improve the VERITAS Facility to assure wide-ranging capabilities and state-of-the-art resources.

ENHANCEMENTS TO THE VERITAS FACILITY

The equipment purchased with this award has been used to enhance the VERITAS facility, which is owned and operated by Wright State University, but housed at the Air Force Research Laboratory at Wright-Patterson AFB. This facility includes a *CAVE*™, which is a highly immersive wide field-of-view, stereoscopic, real-time interactive graphical display system. The *CAVE*™ in the VERITAS facility consists of four walls and a floor, each 10x10 feet, all of which display imagery generated by a *Silicon Graphics (SGI) Onyx*™ multiprocessor computer with *InfiniteReality*™ graphics and projected by high-resolution *Electrohome M8500* field-sequential stereoscopic projectors (rear-projection for the four walls, top-projection for the floor). The user's head and hand position are monitored by an *Ascension Flock of Birds*™ magnetic tracker, to provide real-time perspective correction (head tracker) and real-time interaction with virtual objects (hand tracker). The user's head position also provides the basis for the rendering of spatial audio. Stereoscopic images can be seen when the user wears *Stereographics Crystal Eyes2*™ LCD shutter glasses.

Hardware Upgrades. The DURIP funds were used to purchase three state-of-the-art, high-performance computer subsystems: a multiprocessor computational subsystem, a graphics generation subsystem, and an acoustics generation subsystem. Additional funds were used to purchase a second multiprocessor computational subsystem, expansion memory, haptic interfaces, workstations, and a variety of software.

A multiprocessor computational subsystem from *SGI* for the *Onyx*™ computer at the VERITAS Facility was purchased with DURIP funds (a second subsystem was purchased using

other funds). Each subsystem includes four 64-bit 200-MHz *R10000* CPUs (with 2 Mb of secondary cache per CPU). These eight CPUs replaced the four 32-bit 150-MHz *R4400* CPUs that came with the original system. The *R10000* represent the latest-generation technology; whereas the four *R44000*s were nearly fully utilized for graphics control alone, with only limited resources available for the model simulation (e.g., flight dynamics models), the eight *R10000*s provide a significant increase in the computational resources available for simulation, permitting the implementation and evaluation of more complex, more realistic object models, high-fidelity simulation of flight dynamics, and real-time simulation of tactical scenarios. Also, the upgrade to 64-bit CPUs permits us to fully utilize the advanced capabilities of the 64-bit version of the *SGI IRIX 6.5* operating system that is required for full support of the *InfiniteReality*™ graphics generation subsystems.

A second *InfiniteReality*™ graphics generation subsystem from *SGI* was added to the *Onyx*™ using DURIP funds. Each graphics subsystem has an output video bandwidth of 624 Mpixels (textured, multisampled, antialiased, and z-buffered) per second, can generate 10.9 million polygons per second, and has either 16Mb (the first graphics subsystem) or 64Mb (the second graphics subsystem) of texture memory. The addition of the second subsystem more than doubles the graphics capability of the *Onyx*™. The *InfiniteReality*™ architecture allows considerable flexibility when determining how the graphics resources are distributed across the five projectors (four walls and the floor) of the *CAVE*™. The trade-offs among total number of active channels, resolution, refresh rate, etc., are complex but are supported by software tools on the *Onyx*™ allowing us to generate a wide variety of video combinations. For example, the CAVE™ floor, four walls, and a workstation monitor for the user can all be simultaneously driven at 120-Hz stereo (60 Hz per eye) with a resolution of 800 X 800 pixels. However, higher-resolution can be achieved by reducing the number of displays (e.g., four simultaneous 1280x1024-pixel 120-Hz stereo displays on four surfaces of the *CAVE*™) or mixing resolutions (e.g., 800x600 resolution on rear wall, side walls, and monitor, coupled with 1280x1024 resolution on the front wall and floor).

A *Huron-20* digital acoustics generation subsystem from *Lake DSP* was purchased using DURIP funds. Before the purchase, the VERITAS facility had no dedicated audio generation capability. The *Huron-20* is configured with 16 *Motorola 56002* Digital Signal Processors, each capable of 20 million (24 bit X 24 bit) multiply-and-adds per second. It can apply spatial filtering to 128 virtual sounds, which can be allocated as sources, echoes, or reverberation. It can be used to drive headphones or up to 16 loudspeakers that can provide unencumbered, no-headphone, spatialized audio via the included *Lake DSP* software. The *Huron-20* and *Lake DSP* software is compatible with the *Paradigm Vega* software used to generate simulations in the *CAVE*™.

Non-DURIP funds were used to purchase additional main memory for the *Onyx*™. The original memory configuration, 256MB, was adequate for the four *R4400* CPU configuration, but the upgrade to eight *R10000* CPUs required a corresponding increase in main memory to 512 MB.

Non-DURIP funds have been used to purchase input devices, including a haptic interface. The original input device for the *CAVE*™ was a *PinchGlove*™, which permitted the capture of only simple hand gestures (finger closures or "pinches"). A passive joystick and throttle (*F-22 Pro and F16-TQS, Thrustmaster*), and a force-feedback joystick (*IE-2000, Immersion*), which is being

used to provide haptic stimulation (e.g, force cues proportional to approach and/or glide slope error in the context of a landing task), have been added. Additional funds were used to purchase a Pentium PC for control of the *IE-2000* haptic joystick.

Finally, non-DURIP funds have been used to purchase two *SGI O* 2 workstations that permit development of new applications for the *CAVE*™ while experiments are running on the VERITAS *Onyx*™.

Software Upgrades. Non-DURIP funds have been used to purchase upgrades to our high-performance image generation software, software for high-fidelity simulation of flight dynamics, and software for generation and simulation of tactical engagement scenarios.

The software used to generate the visual simulations in the *CAVE*™ is *Paradigm Simulation, Inc.'s (PSI) Vega.* Initially, VERITAS had a single base license for *Vega.* Additional base Vega licenses for program development and *Vega* modules needed to support various research projects have been added. Specifically, the *VCR* module is used to collect data by recording simulation information on a frame-by-frame basis; the *Symbology* module allows simulation data to drive virtual instruments (e.g., primary flight display); the *Large-Area Database Management* module allows simulations to use terrain databases ("virtual worlds") that are larger than main memory; *AudioWorks* interfaces the simulation to the *Huron-20* digital audio subsystem. Additional *Vega* base licenses were purchased to permit the simultaneous operation of the *CAVE*™ and applications development on the two *SGI O* 2 workstations. We also obtained from *PSI* a geo-typical terrain database (*Vampire*), 60km x 80km in extent, providing a wide variety of terrain types, suitable for out-the-window scene generation in the simulation of high-velocity, low-altitude flight.

For research projects requiring high-fidelity simulation of flight dynamics, we obtained *Virtual Prototypes, Inc's (VPI) FLSIM*, which provides both a dynamics simulation engine and a database editor that is used to graphically display and modify the specific aerodynamics data of the vehicle to be simulated. Aircraft databases provided with *FLSIM* include: F-16, KC-135, B-747, and C-140. The graphical database editor simplifies the creation of aerodynamics databases for other fixed-wing vehicles.

Also from *VPI*, we obtained the tactical scenario generator and database editor *STAGE*, which is used to simulate the behaviors of targets and threats in, for example, a simulated integrated air defense system. *STAGE* provides the ability to import the terrain database used for visual simulation in *Vega* and incorporate the resulting geophysical constraints in the tactical simulation. The graphical database editor simplifies the creation of scenarios containing specific instances of a variety of targets and threats.

Both *FLSIM* and *STAGE* are designed to be extensible and integrated into larger simulations. We obtained from *VPI*, user-module code that provides this integration with our *Vega* visual simulation. The CPU upgrade allows for one CPU to run the *FLSIM* flight dynamics simulation, and another CPU to run the *STAGE* tactical scenario simulation, with the remainder dedicated to the *Vega* visual simulation.

Current Status. These upgrades have been selected, evaluated, purchased, installed, and integrated. The multiprocessor computational subsystems, along with the additional memory, allows more complex simulations to run at higher frame-rates, including realistic flight-dynamics.

The additional graphics generation subsystem more than doubles the video resolution and more fully utilizes the capacity of the projectors. The acoustics generation subsystem will allow us to present complex auditory environments, including acoustic reflections and reverberation. The haptic stick allows us to examine various strategies using force-feedback to provide information to operators (e.g., "force tunnels"). The two additional workstations allow simultaneous program development and experimentation. New software provides high-level tools and off the shelf solutions to a number of identified project needs and have allowed us to implement a high-fidelity simulation with realistic (as indicated, for example, by the reports of pilots) flight dynamics.

VERITAS as currently configured is one of the top projected-virtual environment facilities in the world. It offers wide-ranging capabilities, but has been designed so that programmers with relatively little experience in computer graphics and simulation can still create and/or modify complex virtual environments, flight simulations, and tactical scenarios. Although every virtual environment generation strategy has limitations, VERITAS is well-suited to our DoD-related research, allowing the integration of real (e.g., the user's hand or a cockpit mock-up) and virtual objects, 3D rendering of visual displays such that both near (e.g., cockpit instruments) and distant (terrain) virtual objects can be simultaneously appreciated, realistic spatialized audio, and haptic feedback via stick forces. The facility can be configured to provide a compelling pilot-centered flight simulation with realistic flight dynamics, but can also be used to simulate other command and control representations, including traditional operator workstation, "data wall," and 3D God's-eye/sand-table for tactical and strategic planning.

SUPPORTED PROJECTS

Much of the current work at the VERITAS facility is funded by a grant from the Air Force Office of Scientific Research [F49620-97-1-0231] and focuses on the design and evaluation of displays and controls for the operation of Uninhabited Aerial Vehicles (UAV). This project will establish necessary and sufficient information constraints for effective man-in-the-loop control of UAVs, and thereby help to specify the range of missions and operational environments where UAVs can be reliably used. This collaborative project involves several faculty members from the Department of Psychology (Kevin Bennett, John Flach, Robert Gilkey, Scott Isabelle, Valerie Shalin) and their graduate students (Jeff Calcaterra, Michael Payne, Matthew Smith, Billy Jack Crawford, Brian Simpson, Paul Jacques), and two faculty from the College of Engineering (Jer-Sen Chen, Jennie Gallimore) and their graduate students (Jessie Lucas, Nathan Brannon, Arti Kulkarni, Lakshmi Yechuri, Xing Xu). Interactions with Air Force personnel have been encouraged by this project (Sam Schiflet and Linda Elliot at Brooks AFB, Elizabeth Martin at Williams AFB, Daniel Repperger and Michael Haas at WPAFB, Curtis Spenny at AFIT). Haas, Repperger, and Spenny are currently collaborating with members of our group on related projects. Interactions with Navy personnel (LtCmdr Fred Patterson at NAMRL Pennsicola)have also been enhanced by this project.

This project strives to develop a basic understanding of cognitive workload and situation awareness relative to the performance and functionality of complex socio-technical systems. Toward this end we are implementing a complex synthetic task environment that includes critical elements of a SEAD mission; we are performing and evaluating a multi-component task analyses of

the SEAD mission and various telerobotic systems, in order to identify critical task components and sources of cognitive workload; we are performing targeted studies of sensory and perceptual capabilities and limitations that may impact cognitive workload; we are designing display and control interfaces that directly represent the functional impact of commands and the semantics of environmental information, and will evaluate these displays in terms of their influence on performance and cognitive workload; and we will evaluate the constraints on human performance and cognitive workload in telerobotic and virtual display systems such as Uninhabited Aerial Vehicles (UAVs), including level of automation, bandwidth, delays, and reliability.

Research on spatial hearing funded by AFOSR[F49620-95-1-0106] has also benefitted from the equipment purchased for VERITAS. This project is using psychophysical measurement and modeling to determine the acoustic cues that mediate human sound localization in real and virtual environments. The project has supported Robert Gilkey and Scott Isabelle, and graduate students Brian Simpson and James Kondash. The *Huron-20* has been used to analyze room acoustics, such that realistic echoes and reverberation can be presented in virtual environments at VERITAS. Although funding for this project has now ended, our efforts to determine the impact of room acoustics on localization performance, multichannel communication, and the sense of presence in virtual environments will continue.

A number of other projects are also benefitting from the enhancements to VERITAS. These projects examine issues such as the use of virtual environment technology in medicine, data visualization, and collision avoidance.

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